Breakthrough in Japanese Railways 8

Railways and Bridges

Junichi Konishi

Railway Construction under British Engineers: Early Bridges

Although the coffers of the Meiji government at the end of the late 19th-century were not overflowing, it decided on a policy of building railways itself by borrowing money from Britain. Railway construction started between Tokyo and Yokohama and between Kobe, Osaka, and Kyoto under the oversight of British engineers because no Japanese engineers had learned railway technology at that time.

The first Chief Engineer was 29-year-old Edmund Morel who arrived in Japan in April 1870. In addition to technical instruction and overseeing of railway construction, he gave important advice on technical administration and education, leading to the establishment of the Ministry of Works (1870) and Imperial College of Engineering. Morel died of illness in November 1871 before the opening of the railway in Japan. While he only served for 18 months, he played a key role as an advisor on railway construction and in Japan's later modernization as a whole.

Japan's first railway opened in 1872 between Shimbashi and Yokohama; it was a rushed project so the required iron bridges were not ready and all the first bridges were temporary wooden structures. The largest, Rokugogawa Bridge, had a queen post truss with seven spans measuring 55 ft between piers crossing a river on the Kawasaki side, and a girder bridge crossing the dry riverbed on the Shimbashi side. The abutments were marvellous brick structures, but the central piers were a series of wooden columns. The bridge floor was planked for dual track with rails laid for only one track at the opening. The track was secured on longitudinal sleepers. Rebuilding of Rokugogawa Bridge and other major bridges as iron bridges began 3 years after the line opened.

The Kobe to Osaka line (opened 1874) started slightly later than the Tokyo to Yokohama line with Japan's first iron railway bridges crossing the Jusogawa, Kanzakigawa, and Mukogawa (*gawa* is Japanese for river). Other rivers were again spanned by temporary wooden bridges. The iron bridges had iron tube masts joined to screw piles as piers with pin-jointed wrought-iron truss girders (called lattice girders at the time) on top. The span between pier centres

Portrait of Edmund Morel
(The Railway Museum)

First Rokugogawa wooden bridge (1872) on Shimbashi–Yokohama Line
(Institut des Hautes Etudes Japonaises, College de France)

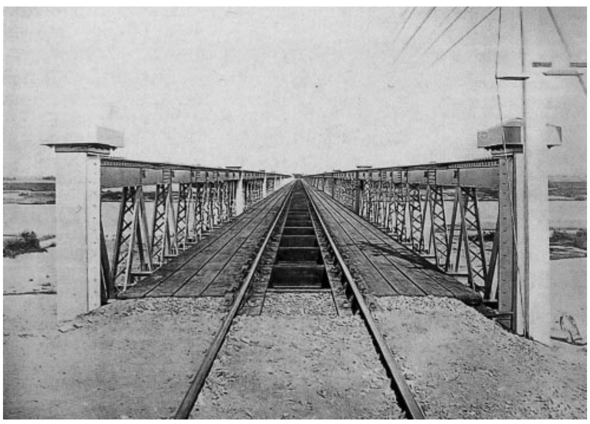
was 70 ft (21.3 m), so they were short for truss girders. All three bridges used the same girders, possibly making them the first standardized girder design. Three tunnels were constructed under riverbeds on that section. Brick arch bridges were constructed where embankments crossed small rivers, channels, paths, etc.

Later construction between Osaka and Kyoto (opened 1896) used iron designs for all main large and small bridges. The largest girders were all wrought-iron, pin-jointed truss girders with a clear span of 94 feet and were 99 feet 10 inches long overall to bridge the 100 feet between pier centres. They were erected across the Kamijusogawa, Kamikanzakigawa, Ibarakigawa, Otagawa, and Katsuragawa.

The earlier wooden Rokugogawa Bridge in the section between Shimbashi and Yokohama was rebuilt with double-track truss girders of the same structure and span as used for the aforementioned bridges between Osaka and Kyoto.

The truss girders were designed under the supervision of technical advisor Dr William Pole in Britain based on Japanese schematic designs and were manufactured in Britain. On-site construction was completed under the oversight of the British engineer Theodore Shan.

The 70 and 100-ft girders featured thick frames with upper and lower chord members and end posts, and relatively thin diagonal braces assembled in the Warren style by pin jointing. This is a proportion commonly seen in British small- and mid-sized trusses of the time, but pin jointing was probably used taking into consideration that they were for Japan with a low technical development. The cross beams supporting the track were laid at equally spaced intervals on the chord members rather than the panel point section. Also, the stringers were not directly under the rails at first; thick longitudinal sleepers were laid on the crossbeams. Arranging crossbeams closely with thick longitudinal sleepers distributed the load on the lower chord members, rather like a wooden construction. This is contrary to American-style pin-jointed trusses, which concentrate the load on panel points in accordance with elementary truss theory. Thus, high-level theory would probably be required for a strict analysis of this structure. The design live load used assumed continued use of small locomotives and ignored any future increases in locomotive size.



First iron railway bridge in Japan, Shimokanzaki-gawa Bridge (1874) on Osaka–Kobe Line (S. Onoda)

Short-span plate girders were either imported from Britain or manufactured at the government railways' Kobe Works using imported materials. Railway workshops for repairing rolling stock had equipment for cutting, bending, punching, riveting, and forge welding of iron so plate girders could be manufactured.

Upgrading from wooden to iron bridges on the Shimbashi to Yokohama and Osaka to Kobe sections was carried out from the larger spans first and the plate girders used for the upgrades were manufactured at the Shimbashi and Kobe Works.

Acquiring Technologies

Although Japan's railways were supervised at first by British engineers, the first Chief Engineer Edmund Morel stressed the importance of training Japanese engineers so future railways in Japan could be built by Japanese. Masaru Inoue, Director of the Imperial Government Railways, took his advice and set up a technical training school in Osaka in 1877 to train employees so the railways could become independent as quickly as possible. As a result, Japanese engineers were able to construct the Osakayama Tunnel between Kyoto and Otsu without the help of British engineers. The wrought iron plate girder design of the Kamogawa Bridge (opened in 1879) on the same section was by Amane Mimura, a graduate of the technical training school, under the instruction of principal engineer T. R. Shervington who lived in Kobe. It was the first plate girder railway bridge designed by a Japanese. Japanese engineers developed abilities while working under the instruction of British engineers. Later bridge design was done under the instruction of C. A. W. Pownall, who was principal engineer from 1882 to 1896. Technical training school graduate Seiichi Furukawa worked continuously under Pownall on bridge design, and he participated in major projects, such as the arch bridges at the Usui Pass section of the Shin'etsu Line. He later designed the Amarube Viaduct (steel trestle, 1912) on the San'in main line.

By the time Pownall returned to Great Britain, the number of Japanese who had studied in the USA and Britain had increased greatly, and bridge design was done by Japanese. However, design of large truss girders was commissioned to American engineers around 1897, and all design was not done by Japanese until 1911.

Establishment of Standard Girders

With iron plate girders, a method to decide the span arrangement by designing multiple types of girders of a set length and combining those was adopted at a relatively early stage. Principal engineer Pownall, who arrived in Japan in 1882, added newly designed girders to existing designs, standardizing six types of plate girders with clear spans of 20 to 70 ft in 10-ft intervals in 1885. Later, Pownall designed 20 to 40-ft steel standard plate girders in 1893 and 1894 with the main material changed to steel. These British-style plate girders have features such as wide cover plates around the entire circumference at the top, bottom, front and back ends, T-shaped stiffeners to reinforce web plates that curved around top and bottom ends to avoid angles and riveted to cover plates, forge-welded struts and stiffeners connecting the right and left girders to form a unified square shape, and no diagonal members. Girder height was also smaller than later American-style plate girders.

The engineer Bunzo Sugi designed 20 to 80-ft steel girders to American standards in 1902 as new standard girders, marking a change from British to American style. After nationalizing private lines in 1906–07 the government railways worked to unify standards. Bridge live loads followed the Cooper's E33 standard, and improved standard plate girders were designed in 1909. Standard girders with cast-iron supports were designed in 1919, and even larger standard girders were designed the following year for the E40 live load. These structures hardly changed even after the 1928 adoption of the metric system and were used until the end of riveted structures.

The girders of larger spans were truss structures. Many with the almost 100-ft span adopted for bridges on the Osaka to Kyoto section were produced as standard girders for the Tokaido main line, Nippon Railways, and others. Trusses of the same design were produced in steel from about 1893 mainly for double-tracking the Tokaido main line.

Appearance of 200-ft Trusses

Pownall designed trusses with a span twice that of Warren pony trusses (100-ft long with clear span of some 94 ft) to build bridges on the Tokaido main line from Tokyo to Kyoto. These new trusses had a clear span of 200 ft (60.96 m) to cross large rivers. Unlike with previous procedures, Pownall drew the detailed designs and sent them to T. R. Shervington in Britain for checking before making some adjustments and ordering manufacture by the Patent Shaft and Axletree Co. Ltd., in Great Britain. The entirely wrought iron pin jointed double Warren trusses (called truss girder or lattice girder at the time) had crossbeams placed at equal intervals on lower chord members and were surface bearing as with

Ibigawa Road Bridge (1887) converted from Tokaido Main Line Railway Bridge (Author)

Oigawa Bridge, Tokaido Line with 200-ft truss for live load E45 (Author)

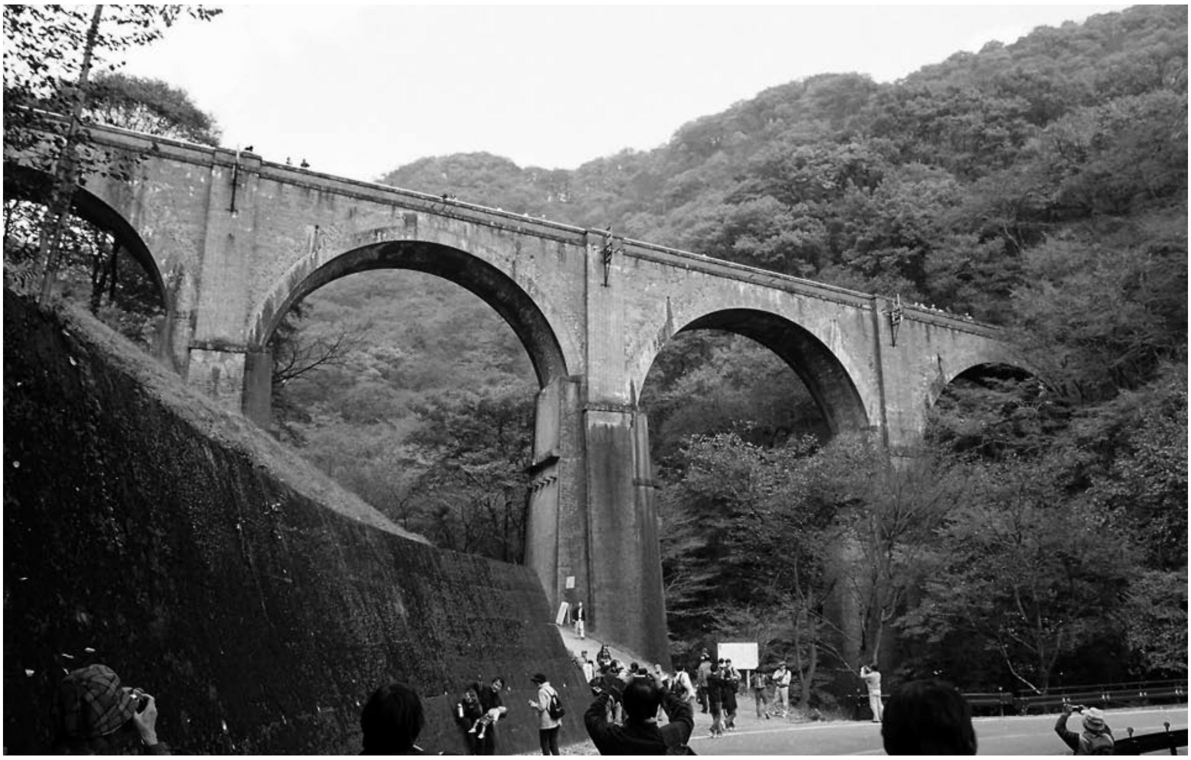
100-ft girders. A total of 22 were used on bridges over the Tonegawa, Ibigawa, Nagaragawa, and Kisogawa.

Then, a total of 90 double Warren truss girders of the same skeleton whose wrought iron main members were replaced with steel members, were manufactured in England and erected in the Hakone area, crossing the Fujigawa, Oigawa, and Tenryugawa on the Tokaido main line, the Saigawa on the Shin'etsu Line, the Tonegawa on the Joban Line, the Tonegawa on the Ryomo Line, and the Kiso, Nagara, and Ibigawa on Kansai Railways.

This 200-ft span became standard for Japanese railways for a long time. The government railways did not adopt, truss girders with spans of more than 200 ft until three trusses with 300-ft spans were imported from the USA in the late Meiji period and installed on the Chuo Line and Ou Line.

Kyushu and Hokkaido

Following the early example of the government railways, private railways in Honshu used British-style bridges, but the early Kyushu Railways were of German design and manufacture because the Chief Engineer was Hermann Rumschoettel. The Chitosegawa Bridge over the



Usui No. 3 Bridge of old Shinetsu Line (1892), now used as foot bridge for walking trail (Author)

Chikugogawa on the first section had 100-ft and 150-ft span parallel cord pin-jointed Pratt trusses made by Union. Later truss girders were all Harkort pin-jointed bowstring truss girders developed for underdeveloped countries with 100, 150, and 200-ft spans. Materials and dimensions were metric, and they were promoted as not using rivets at the worksite, allowing easy assembly. They had a small design live load and could not handle the rapid increase in transport volumes and heavier locomotives, so they were removed from trunk lines relatively early.

In Hokkaido, American engineers were hired for railway construction so wooden bridges were used widely in the fashion of a pioneer railway and there were also wooden trusses. American iron pin-jointed trusses (100 and 150-ft spans) were used in 1882 on the Horonai Railway.

Usui Pass Brick-Arch Bridge

Another remarkable job by Pownall was the construction of the steeply graded section at the Usui Pass on the Shin'etsu Line between Yokokawa and Karuizawa. In selecting the route for this section, Pownall stressed that it should be built at the standard steepest gradient (25‰) because it was part of the trunk line. However, the terrain from Yokokawa to Karuizawa was all up grades, so the pass could not simply be tunnelled and it was impossible to build a standard grade line. Japanese engineers decided they would need to use a special method employing the Abt rack and pinion system to overcome the steep 66.7‰ grade; construction started with the section opened in 1893. All the bridges built on the steep grade were all-brick arches. The No. 3 Usui Bridge consists of four arches, and is the largest in the section at 91-m long and 31-m high, making it Japan's highest brick bridge.

Switch from British to American Style

Imperial University Professor Canadian J. A. L. Waddell and Pownall debated the relative merits of British and American style bridges in a Yokohama English language newspaper in 1886, sparking a war of words over British and American style bridges. As the number of Japanese who had studied in the USA increased and Imperial University graduates became more professionally active, the movement away from exclusively British methods gained momentum. In 1893, the Director of the Railways Agency changed from Masaru Inoue who had studied in Britain to Soichiro Matsumoto who had studied in the USA. The influential Pownall returned to the UK in 1896. As a result, bridge design changed gradually from British to American style.

The government railways commissioned prominent American bridge engineers Theodore Cooper and Charles Conrad Schneider to design new truss girders to handle the heavier trains. A total of ten types of standard trusses were designed: 100, 150, and 200-ft clear span deck and through trusses; 100 and 200-ft through trusses including those for double track; a skew 200-ft through truss and 300-

ft through trusses. From 1899, most were made in the USA and were installed on lines under construction, lines being double-tracked, and as replacement bridges on the Tokaido main line.

Some private railways started using American style bridge girders from 1896. Private railways in the Kansai region predated government railways in adopting spans greater than 200 ft. In 1899, Hankaku Railway and Kiwa Railway imported 250-ft class pin-jointed curved cord trusses with subdivided panels from the USA. The same year, Kyoto Railway imported 280-ft pin-jointed curved cord Pratt trusses from the USA and installed them on the Hozugawa Bridge.

American pin-jointed truss girders of Ibigawa Bridge (1900) on Tarumi Railway (Author)

It would be 1907 before the government railways imported 300-ft trusses and erected them on the No. 1 and No. 2 Kisogawa Bridges on the Chuo Line.

At the end of this period, a new truss design for cantilever designs was adopted for three bridges on the Ban'etsu Line over the Aganogawa opened in 1913 and 1914. The Amarube Viaduct opened in 1912 on the San'in main line was a viaduct with high trestle piers designed by Seiichi Furukawa who had been Pownall's assistant. Trestle piers were imported from the USA and the girders were made in Japan. The bridge was removed in 2010 when a new bridge was completed.

Switch to Rivet Jointed Trusses and Design and Manufacture in Japan

Railway works started manufacturing plate girders early on in Japan, but truss girders were imported from Britain and the USA for a long time by the government railways and Railway Agency. The last imported trusses were made in 1913.

Imports were relied on for truss girders because the tension members called eye bars for pin-jointed trusses were hard to manufacture. However, from about 1905, the Governor-General of Taiwan Railways, commissioned mass-production in Japan of pin-jointed truss girders designed by Cooper and Schneider that were the same design as those of the government railways. This suggests that the government railways probably did not trust private-sector

Former Amarube Viaduct constructed in 1912 and dismantled in 2010 (Author) manufacturing technology. American style pin-jointed trusses of the time were clear in theory, but live loads are larger than dead weight for 300-ft or shorter trusses adopted by Japan. As a result, large sway and vibration commonly damaged various parts, such as eye bars. Soji Okoto, who had studied in Germany, realized that German truss girder panel points were all rivet jointed. Upon returning to Japan, he proposed that standard trusses be rivet jointed instead of pin jointed, and he set about producing them in Japan. The first were designed at live loads for standard gauge (1435 mm) trunk lines (E45) to replace British 100 and 200-ft trusses on the Tokaido main line designed in 1911 and 1912. While some were manufactured in the USA, most were the first truss girders commissioned by the government railways from private-sector manufacturers in Japan. Electric railways were soon opening in quick succession in large urban areas, such as Tokyo, Osaka, and Nagoya, and American style tall and light rivet jointed trusses were adopted with design and manufacture completed in Japan. The first is believed to be the Yodogawa Bridge of Hanshin Electric Railway in 1905.

The different standards of the various railways were unified after the 1906-07 railway nationalization and an organization specializing in design of railway infrastructure was established. Bridge design live loads were set as Cooper E33 in 1909, and new standard girders meeting that specification soon appeared. There were seven types of new standard girders for deck plate girders from 20 to 80 ft. Standard through plate girders were established in 1910 of the same span and live load.

The first design specification for steel railway bridges for government railways was established in 1912. They followed the American standards, and the basic specifications did not change even with the switch to the metric system.

Cast-iron shoes were added to the 1919 design specifications, which was an update of the 1909 version. Deck plate standard girders with a live load of E40 were established in 1920. Standard girders switched to metric in 1930 and had eight spans from 8.2 m to 31.5 m corresponding to live loads of KS18, 15, and 12. KS18 corresponds almost identically to E40, and likewise KS15 to E33 and KS12 to E26.

Attempting New Forms

Various new structures were designed and built from the 1920s to 1930s, a period when many standard bridges were constructed.

Rigid frame bridges

Rigid frame bridges that merge plate girders and steel columns were designed and built in urban areas. These include the Yodobashi Overbridge (1922), Iidabashi Underbridge (1926), and Suidobashi Underbridge (1931).

Trestles

Bridges with the same truss structure piers as the 1912 Amarube Viaduct—trestle piers—were erected over deep mountain gorges. Five bridges of the former JNR used this structure, including the Tateno Bridge (1928) and No. 2 Hirosegawa Bridge (1931).

The Nakakosawa Bridge on the Koya Line of Nankai Electric Railway is a Greek π-shaped viaduct combining trestle piers and truss girders. It is the only railway bridge of this type still standing today.

Curved girders

The Manseibashi Underbridge (1928) on the Chuo Line had curved girders matching the line curve radius.

In 1932, a truss girder was designed and constructed that was bent at the panel points to match the 300-m radius of the line at the Iyogawa Bridge on the Dosan Line.

Suidobashi viaduct (1931) over Hakusan Street (Author)


Manseibashi bridge on Chuo Line (Author)

Yodogawa Bridge (1928) on Kyoto Line of Kintetsu Railway (Author)

Yoshinogawa Bridge on Kotoku Line (Author)

Sumidagawa Bridge on Tobu Line (Author)

Sumidagawa Bridge (1932) on Sobu main line (Author)

Huge truss girders

Nara Electric Railway's (now Kintetsu Kyoto Line) Yodogawa Bridge opened in 1928 had double-track curved cord Pratt trusses with subdivided panels (Pennsylvania truss). It was very large, with a 540-ft (164.6 m) span, radically surpassing the government railway's largest bridge, a pin-jointed single track truss with a span of 306 ft 3 in (93.3 m). That span is still the largest single span truss. The original bridge plan was an ordinary plate girder bridge of several girders, but the bridge location was at an army river-crossing training ground, and the commander would not allow a bridge pier there. His unreasonable demands, rather than technical necessity, forced construction of huge truss girders never seen before in Japan. The bridge featured a design by Shigeki Sekiba, imported American steel, manufacture at the Hyogo Works of Kawasaki Shipyard, and construction by Obayashi Corp., boasting a high technical level and scale equal to projects in the USA. It does not appear in the history of JNR, but cannot be overlooked.

Cantilever truss girders

Tobu Railway's Sumidagawa Bridge (1931) is a cantilever half through truss, well formed and standing on a par with the various road bridges spanning the Sumidagawa. Structurally, its hinge part stands out. Cantilever truss structures were not used by the government railways.

Continuous truss girders

In 1932, three three-span continuous trusses with 71.2-m spans and a 45.3-m span truss were installed at the Yoshinogawa Bridge on the Kotoku Line. They were the earliest full-scale continuous trusses and drew attention along with piers using pneumatic caisson foundations.

Arch bridges

Japan's first steel arch (solid rib) for railways was the Oshikabuchi Bridge on the Otaki Forest Railway that opened in 1923. However, it was a 762-mm gauge light railway bridge. It was followed by construction of four steel bridges from 1926 to 1930 for a dedicated track (762-mm gauge) for transporting materials to build the Kurobegawa hydroelectric power station. The bridges are the old Kurobe Bridge (spandrel braced balanced arch), Moriishi Bridge (solid rib arch), Atobiki Bridge (spandrel braced arch), and Kanetsuri Bridge (spandrel braced arch) of today's Kurobe Gorge Railway.

JR Freight's Suehiro Bridge at Yokkaichi–bascule movable bridge (1931) (Author)

Special-use bridges include prefabricated military portable truss bridges developed by the army. They could handle various spans and loads by assembling large fully welded structural units that could be moved without heavy machinery.

Movable bridges

The first railway movable bridge where the bridge girders move was the Wada Swing Bridge constructed in 1900 on the Wadamisaki Line in Kobe. No other bridges of that type were constructed for a while, but 14 were eventually built between 1927 and 1960 mainly on harbour port lines. They were bascule and lift types, but there were no swing type bridges. The designs were from Yamamoto Komusho headed by Utaro Yamamoto and from the Ministry of Railways. The largest movable bridge in Japan was the lift type Chikugogawa Bridge on the Saga Line; it now serves as a footbridge after the railway line was abandoned. The only movable bridge still serving as a railway bridge is the Suehiro Bridge (1931) at Yokkaichi Port. It is owned by JR Freight and was designated a national important cultural property in December 1998. ■

A spandrel braced balanced arch was erected for ordinary railways in 1928 at the No. 1 Shirakawa Bridge on the government railways' Takamori Line (now Minami Aso Railway). That was the first government railways' steel arch bridge with a span of 300 ft (91.4 m) but it did not exceed the existing largest span. In 1937, a spandrel braced balanced arch with an arch span of 112 m was designed for the present day Tadamigawa Bridge on the Tadami Line. It opened in 1941, setting a new record for the largest span.

The Sumidagawa Bridge (1932) on the Sobu main line was Japan's first full-scale deck-stiffened arch bridge, and its central span of 96 m set a new record for the largest government railways' span. The Matsuzumicho Underbridge on the same line was a braced rib tied arch that also opened in 1932. The two bridges on the Sobu main line had a presence on a par with road bridges spanning the Sumidagawa.

Welded structures

Use of welding technology on railway bridges started in 1931 as a method to reinforce existing plate girders while keeping the bridge in operation. Braces were welded to upper and lower flanges. In the 10 years from 1931 to 1940, some 1300 girders were reinforced by welding.

While not a railway bridge, an overbridge was constructed in 1935 at Tabata Station in Tokyo as the first full-scale welded bridge. It was a rigid frame cantilever bridge with unified girders and piers, having span lengths of 40.5 + 53.0 + 40.5 m, making it the largest in the world at the time.

The first fully welded railway bridge used a small plate girder with a 7.2-m span erected on a test basis in 1941 for the Kabe Line No. 1 Yasu Bridge. It is still in use today.

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